

## Development of Experiential Learning Models in Biomedical Engineering Programs for International Implementation

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## Abstract

Undergraduate biomedical engineering (BME) programs have increased considerably and the drives for continuous improvement of the programs persist. While covering a comprehensive base of multiple disciplines required for BME studies on campus has been a big challenge, the Industry Professional Advisory Committee members usually recommend incorporating experiential learning modules of co-op or internship in the curriculum. Embedding cooperative modules within the undergraduate BME educational program is aimed to assist students in gaining the highly valuable real-life experience. The cooperative work modules facilitate the students in exploring different realistic aspects of the complex work processes in the biomedical engineering field. The values of the cooperative learning modules are recognized by the academicians. It must be emphasized that different countries follow different models for BME education. At the international level, the developers of the BME curriculum find the inclusion of cooperative work experience or internship with a heavy course load in the program a formidable challenge. Having a single model is not likely to work in varying environments coupled with practical training and employment opportunities in different countries. The main objective of the present work is to develop few cooperative experiential learning models for BME undergraduate students that can be applied internationally and to propose multiple partner organizations to host the co-op. In this paper, designs of a few co-op/internship models embedded in the undergraduate BME curriculum and an innovative array of co-op hosting organizations are described. Other models of one semester at a teaching hospital, a medical device company, and at an academic research lab are mentioned. The results obtained clearly support the proposed co-op/internship scheme. In conclusion, integrating the cooperative work experience will be of significant value in biomedical engineering education by giving opportunities for real-life work experience to the students. For sustained success at the international level, it is essential that a suitable model must be selected to blend with the mission of the overall training program at the academic institution.

*Keywords*— BME Cooperative Education, Experiential Learning Models, Hospital Internship

## Introduction

Students tend to understand and master professional concepts and skills more effectively through practical experience than through exclusively classroom-based learning. Literature on engineering education often pays scant attention to the importance of cooperative education and experiential learning [1]. The integration of formal on-campus academic training with cooperative learning modules provides students with both exposure to professional experience and a strong theoretical background, forming a superior educational model for training students in professional programs.

Co-op programs are often adopted in professional studies including medicine, nursing, pharmacy, law, accounting, etc. The goal of incorporating co-op learning modules as a mandatory component of the BME undergraduate program is to assist students in gaining practical experience in the field. Though many programs make participation in such activities available to students, it is generally up to the students to take advantage of experiential learning opportunities [1]. The Industry Professional Advisory Committee members make recommendations for feasible schemes to increase practical experiences for students. The main challenging factors in designing curricula that incorporate experiential learning are time requirements of comprehensive training juxtaposed

with the time restraints due to the heavy course load of multidisciplinary fields such as BME, as well as the lack of availability of suitable collaborators to provide cooperative work experience to students.

While undergraduate programs are not fully developed in many countries, a baccalaureate degree in BME requires the completion of a multitude of courses in different basic science and engineering disciplines, as well as biomedical engineering. Clinical Engineering and Biomechanics, for example, are considered sub-specializations within the Biomedical Engineering domain for which there are not many programs offering cooperative work experience training [2]. A significant amount of interaction with hospital staff such as nurses, clinicians, and facility engineers is required for a Clinical engineer working at a hospital. Meeting this requirement while reasonably managing the total number of academic credits severely constrains the available time to assign practical work experience. Designing courses to adequately train students to meet the demands of biomedical industrial or clinical settings is difficult.

Cooperative work models facilitate the students in exploring realistic aspects of work processes in the field. On-the-job training truly complements what the students learn in classrooms and labs. Cooperative work modules allow students to apply their engineering expertise and medical equipment knowledge while learning about complex clinical settings or how to find solutions to real, practical problems in manufacturing facilities. Well-designed cooperative work experience programs provide training that compliments in-class and in-lab learning in the academic environment [3].

At the international level, limited resources and unpredictable business climates pose a problem for setting up co-ops/internships with biomedical device manufacturers. Small city locations and hospitals face similar problems especially in countries with limited resources and absence of medical device manufacturers. Despite these constraints, incorporating cooperative experiential learning in the BME curriculum has proven to be beneficial and productive in graduating competent and prepared students. The challenge rests mainly with the selection of a suitable model to ensure a good fit for the co-op student, the academic institution, and the host organization.

The objective of the present project is to formulate models for incorporating experiential learning modules in the form of co-op or internships, and to develop an array of collaborators to accept student interns. Based on the success with a limited number of students in six countries, it is felt that the model will be very useful for adoption internationally. This paper describes general BME curriculum requirements and different models for co-op modules, and proposes a wide array of potential collaborating host organizations. This concept will be particularly helpful in countries where they are considering inclusion of internship in their curriculum.

### Designing the Curriculum for BME Major

Over the past two decades, the number of BME programs has significantly increased. VaNTH has proposed clear guidelines for BME curricula [4]. Literature review lends to the observation of wide variations in course requirements in different programs [5].

Developing comprehensive BME programs at the undergraduate level is a challenge [6, 7]. The following clusters of courses often comprise current academic curricula: BME core courses including biomedical electronics, biomechanics and biomaterials, BME capstone projects, design,

and BME elective courses as well as courses in Electrical Engineering and Computer Science, Mechanical Engineering, Math and Physical and Life Sciences. These are often complimented by an array of courses in Humanities and Social Sciences.

Students may be offered a choice of tracks, depending on the emphasis to be placed in the BME program. These tracks include biomechanics, bioelectronics, biomaterials, etc. The selected specialization will determine which courses are appropriate for students to gain relevant expertise. In order to ensure a well-rounded training, related programs have generally begun to increase the laboratory, design, and project components of their curricula [8-10].

In most countries, significant time constraints play a large role in adding cooperative work modules to the general academic curriculum. However, practical experience through embedding internship along with standard professional education programs will constitute a superior comprehensive training for the biomedical students for international adoption.

Alongside time constraints, the availability of suitable sites that have available positions and funding for co-op students is a difficult problem. Possible co-op models and potential collaboration opportunities are described in the following sections.

#### Experiential Learning with Co-op/Internship

Many institutions offer and encourage internship or co-op, but it is not a mandatory component of graduation requirements for most programs in most countries. Co-operative work modules vary between BME programs, and as outlined on their websites, they often extend for different durations [11- 13]. Some opportunities are offered for up to a whole year working full time, while others are shorter, often one semester long or part time. Sometimes even one day or week is all the time that a host organization can offer.

Four models of internship/cooperative work are described in the following section. Model A is a commonly used co-op/internship plan that allows for summer work opportunities [14]. Several summer research programs and scholarships are available to undergraduate students on a national level. These programs are often very competitive. This scheme does not disrupt the standard four year undergraduate program. However, students are only available during a third of a year, which is not typically desirable for host organizations.

#### *Model A: Summer Semester Co-op Option in a 4-Year BME Program*

	Fall	Spring	Summer
First Year	Courses	Courses	
Second Year	Courses	Courses	Co-op
Third Year	Courses	Courses	Co-op
Fourth Year	Courses	Courses	

Model B is designed with two to three cooperative work module interspersed with the curriculum, as shown [13]. Industries prefer this model because it allows them to have an intern or co-op student on board year round. This model, developed by the author, facilitates planning and funding

of activities by the co-op/intern student as well as mentoring and supervision by the host organization.

*Model B: Distributed Three semester Co-op model*

	Fall	Spring	Summer
First Year	Courses	Courses	
Second Year	Courses	Courses	Co-op
Third Year	Courses	Co-op	Courses
Fourth Year	Co-op	Courses	

Models C and D apply to quarter systems offered by some universities. Model C displays a two quarter co-op in a four year program [14].

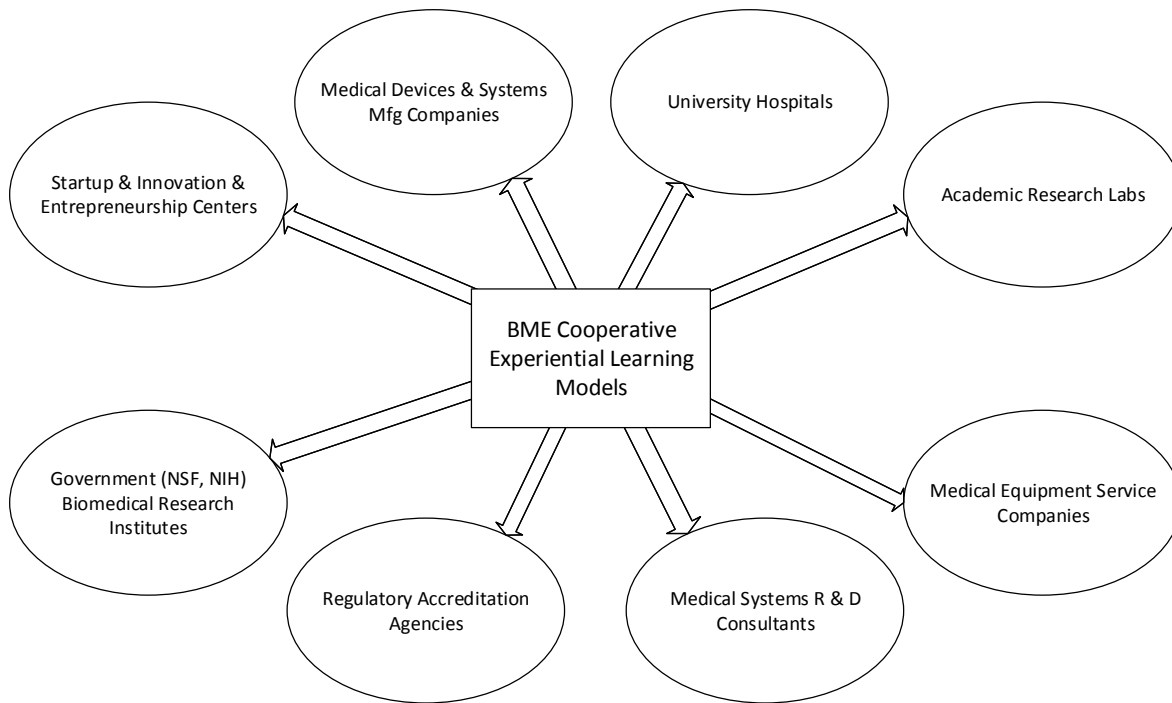
*Model C: Two Quarter Co-op Option in a 14 Quarter Program*

	Fall	Winter	Spring	Summer
First Year	Courses	Courses	Courses	
Second Year	Courses	Courses	Courses	Courses
Third Year	Co-op	Co-op	Courses	Courses
Fourth Year	Courses	Courses	Courses	

Model D represents a six quarter co-op in a five year education program [14]. Students who take part in this program experience 18 months of industrial experience, which greatly enhances their potential for immediate employment after graduation. Two sequential quarter blocks of internship can be carried out at one organization, though students would be able to choose different sites for co-op or internship. This model is not suitable in most countries where a typical duration of B.S. is four years. Several published papers were reviewed to obtain a comprehensive understanding of the internship placement concerns nationally and internationally [15-22].

Obtaining partnerships with hospitals or medical device companies in order to enhance student training is a challenge. An innovative approach proposing a wide array of potential co-op hosting organization is illustrated in Figure 1. This will be particularly helpful at the international level with a varied distribution of resources.

Designing and implementing this plan poses challenges based on diligent assessment of students' academic requirements, prerequisite training, professional interests, and available resources at the training institution. Potential for collaboration at international levels exists at various companies due to the industrial practices toward globalization. These companies may include hospitals, OEM or device manufacturers, research institutions, regulatory agencies, device organization and consultancies. Students must be carefully selected to meet the needs of the collaborators to ensure the success, continuing relationships with such organizations.



*Fig. 1. Potential host organizations for BME Co-op/Internship applicable internationally*

A diverse distribution of potential host organizations with varied opportunities and interests relieves stress from co-op placement administration as well as co-op seeking students. Such diversity will also offer a broader spectrum of BME activities and opportunities for gaining expertise and familiarity. This proposed plan of collaborating with multiple organizations at the national and international levels will enhance the intended comprehensiveness of student training. The level of enthusiasm and productivity displayed by the participating students will pave the way for continuing renewals and expansion of involvement with host organizations. The selection of the co-op model to be employed internationally will vary widely depending on various factors characteristic of the educational organization in the specific country.

## Results

The proposed models started initially with collaboration within one state, Illinois, and extended to organizations in many states in the U.S. Subsequently, the models expanded to an international level, linking students with organizations in Singapore, U.S., Germany, Canada, India and France. Various collaborative efforts and data sources show links between internship experiences with positive results. The experiences and skill sets the co-op students at medical companies gained depended on the division in which they were placed, as well as the products, protocols, and manufacturing processes of the host company. The assignments covered a wide array of divisions from R&D to production, quality assurance, and test engineering, giving the students a broad exposure.

Students placed in hospitals gained knowledge of clinical engineering and a general understanding of hospital operations and protocols. A co-op program with four phases and multiple

activity/training segments at a large teaching hospital has been very successful with students from three universities in U.S., France and Canada. Other students did their co-op at a research center, with service contractors, or with project teams on commissioning and installation of specialized equipment. These students generally prepared a written report with appropriate approval employers.

With the proposed co-op model, graduates are better trained in the BME field. They get valuable experience of understanding real life problems and participating in solving them. They can assess their own interests and develop necessary practical skills to succeed in their careers. Some students can participate in exchange programs on an international scale. The learning outcomes of the students who had gone through experiential learning contributed to comprehensive training of the students. Different models had to be employed to meet the activities and requirements of the co-op hosting organizations. More than 90% of the students felt that the co-op/internship modules enhanced their overall learning. They learned the significant aspects of working in teams, meeting deadlines, dealing with problems and failures, documentation and reporting results. International placement also enhanced appreciation of different working styles, cultures, and solving nation specific problems, as well as networking concepts, all of which could yield long term benefits.

The introduction of BME co-op/internship has been done over several years at various institutions, in the U.S. in Illinois, Massachusetts, Missouri and Georgia and at the international level involved Singapore, France, Canada, India and Germany. There was also international involvement with France and Singapore. Mass General Hospital of Boston, MA, found an eight month position for a masters' student from France, multiple six month positions for undergraduate students from Northeastern, and another position for a graduate student from Tufts. In Illinois, positions for BME interns have been found for students in fifteen hospitals, three manufacturer's offices, and three service companies. Other examples include the Veterans Administration Hospital in St. Louis and the Emory University Hospital in Atlanta. Internationally, Singapore's manufacturers, companies, and hospitals ranging from five hundred to eighteen hundred beds have been involved. There was limited experience with organizations in Canada, France, India and Germany.

Based on personal experience with co-op program in six countries over several years, the value of the co-op programs in providing experiential learning has been observed. The effectiveness of the co-op modules were assessed based on personal interviews with the students after the internship using the following parameters: exposure to real life problems, acquisition of generic skills, improvements in soft skills, bridging the gap from classroom to workplace, student satisfaction with their work experience, planning and organization, self-assessment, improved learning skills, and the potential of getting jobs after graduation.

The impact of the co-op was assessed by individual interviews with students in Illinois and Singapore. There were typically three interviews the first one being informational conversation and specifying expected outcomes. During the co-op, the faculty visited the students on site and held meetings with both the student and co-op supervisor discussing various assigned tasks and student's performance. The third interview was at the conclusion of the co-op to obtain information on the overall learning and impact of the experience. Students were also expected to make a brief presentation describing various aspects of the experiential learning experience at the host institution. Students and the host organizations expressed varied experiences depending on the specific student and the organization, mostly positive. The students felt that they learned the

operations in assigned departments carrying out task assisting engineers in design, testing and preparing relevant documentation

In a study on co-operative education, a comparison of students who participated in co-ops with those who did not participate in co-ops, the results showed that students who participated in co-ops had higher GPAs than that of their counterparts [23]. Similarly, enhancements were observed in student's abilities to learn how to learn, solve problems, think analytically, improve performance in the classroom, increase short term goal realization and strengthen long term goal formation [23]. Results from a survey indicate a link between the amount of preparation, level of interest and the success of co-op. Surveys were distributed at periods before and after the four years of education [24]. The survey results conveyed that the likelihood of job offers coincide with proficient academic performance, but also a student's own nature and background can hold influence. Survey questions have to be phrased and framed in a way to elicit thought-provoking and meaningful responses. With the increasing number of student participants, it is intended to formulate a comprehensive survey of before and after the co-op experience of the students and the host organizations in addition to the interviews.

The present work is of relevance in the international setting since the students and the co-op placement covered several countries such as Singapore, U.S., Germany, Canada, India and France. While labs and academic centers may have many common features at the international level, there are distinct differences in the operations at the university labs, research centers and hospitals internationally. In countries without medical device manufacturing facilities it would be appropriate to place the interns in large hospitals and polyclinics. In countries with a cluster of reputable medical device manufacturers, biomedical research centers, the model of operation will be different and in the countries falling in the intermediate range, a suitable hybrid approach can be carried out. Multiple potential partners for internship are proposed in this paper and it is expected that the model that fits in closely with the host organization in a specific country can be followed. Another aspect of the international co-op placement where two or more countries are involved, the co-op program may serve as a catalyst for formation of collaborative research efforts among academicians and partnering organizations in different countries. Thus there is significant value to international co-op placement and collaboration. These features tend to yield long term gains for all that participate namely the students, the co-op hosting organization and the universities.

It is interesting to note that graduates with co-op experiential learning found jobs easier and faster than those without co-op. Based on the practical real-life experience and skill sets gained by students during their co-op/internship, more than 90% of co-op placement programs were considered effective and beneficial to students and achieved their intended goals. Students as well as co-op hosting organizations gave feedback that confirmed the added value of cooperative experiential learning, based on the benefits to the hosts and the students' real-life experience in the work force. While there are several common challenges in the biomedical field globally, there are certainly some nation-specific problems to be addressed. Fine-tuning with co-op programs based on current and emerging issues facing the nation will be essential to yield benefits to the involved entities.



## Discussion

Experiential learning with co-op is a superior way for students to apply of skills learned in the classroom and labs. These opportunities allow students to gain insight into their career field, clarify their career goals, and allow them to make contacts with professionals. These networking opportunities are invaluable and greatly increase the student's chance of being hired after graduation, giving them an edge over the competition. Students are also faced with their strengths and weaknesses during their co-op, allowing them to evaluate themselves and either better themselves within BME or potentially transfer to a different field [25].

Most collaborating organizations provide funding for the students undergoing training in their co-operative placements. Within the internship period, the intern learns various functions in the BME department and can then sharpen and develop their professional skills. In addition to gaining technical work experience, students realize the overall importance of processes of experimentation, meeting deadlines, protocols for confidentiality and nondisclosure, and proper documentation. The co-op experience can be beneficial to the host organization because they are training students who may be a future permanent staff member. Students benefit from familiarization with complex and expensive biomedical systems that are used in therapy practices and diagnostics. Self-confidence can be boosted by international cooperative placements despite the logistical difficulties such as delays in securing work permits and adequate funding [26]. The student is given an opportunity to gain exposure to a possible area of interest without the financial commitment of fully completing their degree requirements. They have a chance to change fields while they are still a student, which would save them both time and money.

Some time constraints and difficulties are inevitable in carrying out Clinical Engineering internship programs, and efforts are to be made to circumvent these hurdles. Early warning signs of lack of adjustment have been reported in students with both motivational anxiety and lack of initial social contacts. Mid-semester reports of provocative behavior by the student can have a significant impact on both learning outcomes and well-being [27].

Future studies will promote the co-op and internship models at the international level to the academic institutions which do not currently include them in their undergraduate curriculum. BME program directors will be sought out for their input in terms of considering experiential learning models for undergraduate BME students. The corresponding pros and cons will be analyzed and the programs will go through continuous improved for sustained success.

## Conclusion

In conclusion, a few models for integrating co-op modules with undergraduate BME curricula and wide array of potential co-op hosting organizations are presented. The results of cooperative workinternship experiences of students fully support cooperative experiential learning in BME. For sustained success, a suitable co-op model has to be selected to blend well with the interests of students and hosting organizations as well as with the academic institution's overall training mission. It is anticipated that the proposed inclusion of internship in academic curriculum and the experiential learning experience will prepare students to meet global biomedical engineering challenges and be successful professionals contributing positively to the global community.

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